Geoindicators Scoping Report for Sleeping Bear National Lakeshore

Strategic Planning Goal Ib4

May 29-30, 2001
Empire, Michigan

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August 2001

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Scoping Summary

Introduction

The National Park Service and U.S. Geological Survey held a geoindicator scoping meeting for Sleeping Bear Dunes National Lakeshore at Empire, Michigan on May 29-30, 2001. The purpose of the meeting was to bring together park staff, geoscientists, and other resource specialists to address the issue of human influences on geologic processes in Sleeping Bear Dunes National Lakeshore. The group used collective knowledge of park geology and natural resources to identify the geologic processes active in the park and human activities affecting those geologic processes. This report summarizes the group's discussions and provides recommendations for studies to support resource management decisions, inventory and monitoring projects, and research to fill data gaps.

Purpose of meeting

The purpose of the meeting was threefold: (1) to identify significant geological processes and features that are part of the park's ecosystem, (2) to evaluate human influences on those processes and features, and (3) to provide recommendations for studies to support resource management decisions, geologic inventory and monitoring projects, and research to fill data gaps. The scoping meeting was designed to use the participants' expertise and institutional knowledge and build on the synergy of the participants through field observations, group discussion, and the exchange of ideas.

Government Performance and Results Act (GPRA) Goal Ib4

This meeting satisfies the requirements of the GPRA Goal Ib4, which is a knowledge-based goal that states, "Geological processes in 53 parks [20% of 265 parks] are inventoried and human influences that affect those processes are identified." The goal was designed to improve park managers' capabilities to make informed, science-based decisions with regards to geologic resources. It is the intention of the goal to be the first step in a process that will eventually lead to the mitigation or elimination of human activities that severely impact geologic processes, harm geologic features, or cause critical imbalance in the ecosystem.

Because GPRA Goal Ib4 inventories only a sampling of parks, information gathered at Sleeping Bear Dunes National Lakeshore may be used to represent other parks with similar resources or human influences on those resources, especially when findings are evaluated for Servicewide implications.

Geoindicator background information

An international working group of the International Union of Geological Sciences developed geoindicators as an approach for identifying rapid changes in the natural environment. The National Park Service uses geoindicators during scoping meetings as a tool to fulfill GPRA Goal Ib4. Geoindicators are measurable, quantifiable tools for assessing rapid changes in earth system processes. Geoindicators evaluate 27 earth system processes and phenomena (Appendix A) that may undergo significant change in magnitude, frequency, trend, or rates over periods of 100 years or less and may be affected by human actions (Appendix B). Geoindicators are used as a framework to guide the discussion and field observations during scoping meetings (Appendix C). The geoindicators scoping process for the National Park Service was developed to help determine the studies necessary to answer management questions about what is happening to the environment, why it is happening, and whether it is significant.

The health and stability of an ecosystem is evaluated during the geoindicators scoping process. The geologic resources of a park—soils, caves, streams, springs, beaches, volcanoes, etc.—provide the physical foundation required to sustain the biological system. Geological processes create topographic highs and lows; affect water and soil chemistries; influence soil fertility, hillslope stability, and surface water and groundwater. These factors, in turn, determine where and when biological processes occur, such as the timing of species reproduction, the distribution of habitats, the productivity and type of vegetation, and the response of ecosystems to human impacts (Appendix D).

Park selection

Sleeping Bear Dunes National Lakeshore was one of the first parks selected for geoindicator scoping and the park was chosen for its unique geologic setting and resources which includes continental glaciation landforms, great lakes, and associated ecosystems (Appendix E and Appendix F). The park was also in the process of updating its General Management Plan and the geoindicators scoping meeting provided information to support the planning process.

Summary of Results

During the scoping meeting, geoindicators appropriate to Sleeping Bear Dunes National Lakeshore were addressed. Of the 27 geoindicators, 17 were recognized as on-going processes in the park. The issues surrounding each geoindicator were identified, and participants rated the geoindicator with respect to the importance to the ecosystem and human influence (Geoindicator table). Park staff rated the significance for park management. A compilation of the notes taken during the scoping session (Appendix G) is included with the report. These notes highlight additional information regarding geoindicators that may be useful to park managers.

Geoindicator table for Sleeping Bear Dunes National Lakeshore

Geoindicators	Importance to park ecosystem	Human influence on geology	Significance for management
GLACIAL AND PERIGLACIAL			
Frozen ground – Cryogenic Deposition (Sand/Ice Layering)	L/U	L	L
AEOLIAN			
Wind erosion	**H**	**H** (locally)	**H** (locally)
Dune formation and reactivation	**H**	**H** (locally)	**H** (locally)
Desert Surface Crusts (Biotic Crust)	U	U	U
GROUNDWATER			
Groundwater quality	**H**	**H**	**H**
Groundwater level	**H**	**L**	**L**
SURFACE WATER			
Surface water quality	**H**	**H**	**H**
Streamflow	M	M	M
Stream channel morphology	M	M	**H**
Stream sediment storage and load	L	M	M
Wetlands (extent, structure, hydrology)	**H**	**H**	**H**
LAKESHORE			
Lake levels	**H**	M	L
Shoreline position	**H**	M	**H**
SOILS			
Soil and sediment erosion	**H**	**H**	**H**
Soil quality	L	**H** (locally)	L
LANDSLIDES			
Slope failure (landslides)	M	L	M
OTHER			
Sediment sequence and composition*	**H**	L	M
H – HIGHLY influenced by, or with important utility for M – MODERATELY influenced by, or has some utility for L – LOW or no substantial influence on, or utility for U – Unknown; may require study to determine applicability	* Sediment sequences and composition is a tool with great significance for enhancing the information base of the park's ecosystem, identifying human influences on the ecosystem, and providing data for management decisions and planning.		

Significant Geoindicators

The geoindicators deemed (1) important to Sleeping Bear Dune National Lakeshore's ecosystem, (2) to have significant human influences, and (3) to be of significance for park management are listed below.

Geoindicators with importance to park ecosystem

Ten geoindicators were identified as important to park ecosystems and include:

Dune formation and reactivation
Coastal dunes are important determinants of coastal stability, supplying, storing and receiving sand blown from adjacent beaches. Dunes also play an important role by providing morphological and hydrological controls on biological gradients. Coastal dunes are prominent features in the park.

Wind erosion
Dune sand is transported by aeolian or wind processes. Movement of sand is important to some plant species in the park. The survival of federally threatened Pitcher's thistle (*Cirsium pitcheri*) requires accumulating sand to thrive and if severed from a sand source the plant communities will not thrive.

Groundwater quality
Groundwater is important for human consumption and use, and also influences ecosystem health and function. Groundwater is important to the support of terrestrial and aquatic habitat and for maintaining the quality of base flow in park rivers and springs. In the park, the ecological significance of groundwater quality is extremely high due to the interconnection of groundwater and springs to surface water (rivers and lakes).

Groundwater level
Groundwater is a major source of water and availability of this resource is essential to support park ecosystems. Natural changes in the water level of Lake Michigan affects the elevation of groundwater table in the park. During a recent high lake level stand, groundwater levels increased and inundated inland forests resulting in tree die-off in some areas of the park.

Surface water quality
Clean water is fundamental to sustaining ecosystems in the park.

Wetland extent, structure, and hydrology
Wetlands comprise about 20 % of the parklands. Wetlands are areas of high biological productivity and diversity. They provide important wildlife and aquatic habitat and are typical sites for human recreation. The wet and dry seasons, as well as, lake levels cause changes in the size of wetlands.

Lake levels
In the park, dune formation, groundwater level, and shoreline erosion are all influenced by fluctuations in the water level of Lake Michigan and the inland lakes. Long-term lake level fluctuations also significantly influence modern dune and beach ridge formation, and shoreline distribution of forest types.

Shoreline position
The park manages about 64 miles of shoreline. Significant shoreline changes have been associated with both natural lake level fluctuations and changes in nearshore sand transport. Future shoreline changes have the potential to affect nearshore and coastal ecosystems.

Soil and sediment erosion
Soil erosion is an essential factor in assessing ecosystem health and function. Erosion can alter or change natural surface hydrology and runoff, and sediment can damage the park's natural resources.

Sediment sequence and composition
Cores in wetlands and lakes provide pollen, spores and seeds, and other micro- and macrofossils in water laid sediments to reconstruct paleo-environments. It is a tool with great significance for enhancing the long-term ecological perspective of the park, identifying human influences on the ecosystem, and providing data for management decisions and planning.

Geoindicators with significant human influences

Geologic processes in the Sleeping Bear Dunes National Lakeshore can be influenced by human activities through extraction of natural resources, alteration of processes, or by visitor use impacts. Additional impacts to park resources can be caused by human activities outside park boundaries. In order to manage ecosystems and natural resources, it is essential to have a fundamental understanding of how human activities impact or alter geologic processes.

Prior to establishment of the park in the early 1970's, the developed area primarily consisted of private homes and some commercial businesses. The local population used the unique resources now existing within the park boundaries for recreation and for limited resource extraction. Prior land use and land management activities include: farms and orchards, private homes, business developments, septic systems, surface sewage disposal, offshore shipping lanes, gravel mining and dumps. While many of these land use activities no longer occur, they have altered and continue to influence geologic processes in the park. Currently, park visitors have locally altered geologic processes. Annual dredging on the Platte River may also affect the hydrologic and geologic processes in the stream and along the shoreline and needs to be evaluated.

Wind erosion
Locally, park visitors significantly alter wind erosion and deposition in the park. Human trampling of dune vegetation has locally accelerated wind erosion of sand dunes near North Bar Lake. This disturbance coupled with low Lake Michigan water levels has caused an isolation of the embayment lake.

Dune formation and reactivation
Human impacts on dune formation and reactivation is variable in the park. However, popular visitor sites, such as the Dune Climb and the Lake Michigan Overlook are highly modified and impacted by foot traffic and social trails. Park visitors climbing the steep dune faces causes displacement of sand and does not allow for reestablishment of natural vegetation.

Groundwater quality
Human activities significantly threaten groundwater quality in the park. Many sources of groundwater contamination exist within and adjacent to the park and include: surface disposal of sewage pumped from septic tanks, dumps, and underground storage tanks.

Surface water quality
The park has many serious threats to surface water quality from human activities. The park's aquatic resources along Lake Michigan have been impacted by offshore shipping lanes. Surface water contamination and pollution includes: oil spills, human sewage and waste disposal, and infestations of zebra mussels. Park lakes have been treated with chemicals to kill snails that host a burrowing flatworm responsible for "swimmer's itch" and some park streams are periodically treated with a lampricide to kill juvenile lampreys and control populations of these exotic species. Park streams are also impacted every year when thousands of non-native salmon return to streams to spawn and die. The fish carcasses contribute excess nutrients to the streams and cause significantly high levels of phosphorus in the streams.

Wetlands extent, structure, and hydrology
Annual dredging at the mouth of the Platte River can cause sudden drops in water level and a temporary dewatering of adjacent wetlands. Park wetlands are also impacted by public and private roads that cut through wetland areas. These roads can disrupt the natural hydrology and function of wetlands.

Soil and sediment erosion
Erosion is a fundamental and complex natural process that is strongly modified by human activities. Human activities can significantly influence soil and sediment erosion in the park. County roads in the park cause gully and surface erosion. The county is interested in opening additional right-of-ways as trails within the park.

Popular visitor sites in the park, such as the Dune Climb and Lake Michigan Overlook have high foot traffic and social trails. Foot traffic can destabilize dune vegetation and alter sand supply to biotic systems in the dunes. Social trails occur in other areas of the park and cause localized erosion and impact aesthetic views in the park.

Soil quality
Human land use has directly affected soil quality in the park. The park and surrounding areas are underlain by poorly developed soils. Farming and logging practices, which began in the late 1800's, caused rapid loss of soil nutrients. Depleted soils from land use, caused most farm in the area of Sleeping Bear Dunes National Lakeshore to fail over a 40-year period. While less than ten percent of the park area was farmed, soil quality is an issue.

Geoindicators with management significance

Geologic processes can have high management significance due to safety concerns, administrative use of resources, and protection of fragile resources from deleterious human activities. It is important for managers to be aware of what geologic processes are active in a park and how to adapt management to address these processes. This knowledge can greatly assist managers in making decisions to protect human safety and natural resources.

Wind erosion
The park currently expends resources to mitigate for the loss of dune vegetation at North Bar Lake and to control and direct human foot traffic. Structural traps are being used to capture sand and stabilize the dunes. Extensive cord mat trails and fences are used to guide visitors and discourage social trails.

Dune formation and reactivation
Visitor use is focused at several popular dunes in the park. Park management is concerned with evaluating and monitoring the impacts of foot traffic and social trails on these features. On the North and South Manitou Islands, human influence on the dune stability is low. Protecting and maintaining the existing natural environment of the offshore islands is extremely important to the park.

Groundwater quality
Groundwater contamination from multiple sources is a serious threat to the park's groundwater quality. Also future development of private lands outside of the park may impact the groundwater recharge areas located outside the park boundary. There is also heavy pressure for gas and oil development in the area. Park management is concerned with groundwater contamination and potential impacts from these developments on the park's groundwater resources.

Surface water quality
Clean water is essential for human consumption and use, as well as, supporting the parks aquatic and terrestrial ecosystems. Multiple sources of contamination and pollution in Lake Michigan from high use shipping lanes and in park lakes and streams are a constant threat to the park's surface water quality. Maintaining and protecting water quality is a management concern.

Stream channel morphology
Annual dredging at the mouth of the Platte River provides access to the lake for fisherman and boaters. While dredging locally alters channel morphology, the current practice of dredging is the least environmentally damaging action to provide safe boater access. Channel morphology issues also include alteration of streambanks, bank protection structures, accelerated streambank erosion at canoe take-outs, and a dam on the Crystal River.

Wetlands extent, structure, and hydrology
The park is concerned about the influence of dredging on the Platte River on the function of the upstream hydrology and wetlands, and the associated ecosystems. There is a lack of scientific information to determine the extent of impacts from dredging activities on wetland functions.

Shoreline position
Shoreline stability related to sand transport can change dramatically from year to year. Future shoreline changes have the potential to impact park infrastructure and are a management concern. A significant portion of the current park budget, about five percent, is spent on addressing issues related to shoreline changes, primarily dredging activities. Dredging spoils deposited at the mouth of the Platte River and North and South Manitou Islands may locally alter shoreline sediment transport, erosion and deposition. The impacts to shoreline processes have not been evaluated.

Soil and sediment erosion
Soil and sediment erosion from foot traffic, social trails is an issue for park management. Many of the impacts occur at a few high visitation dune sites in the park. Determining the rate of erosion at these sites compared to natural erosion rates on adjacent undisturbed dunes could help determine appropriate management of these areas. Gully and surface erosion from county roads located in the park and the lack of long-term road maintenance by the county also may be an issue.

Summary of Results

The following summary of recommendations lists ideas that were discussed during the scoping meeting held in Sleeping Bear Dunes National Lakeshore in May 29-30, 2001. The summary includes recommendations for evaluating human influences, inventory and monitoring, as well as research. Recommendations are not listed in order of priority. If prioritizing projects that are listed becomes necessary, geoindicators that rated high for all three categories (importance to ecosystem, human impacts, and management significance) might be used as a determining factor. At a minimum, the park may want to consider gathering further information about these geologic processes. If the park would like to pursue some of these recommendations or needs geologic expertise, contact Bob Higgins, Chief of Science and Technical Services Branch, Geologic Resources Division, NPS; (303) 969-2018; e-mail: Bob_Higgins@nps.gov.

Recommendations for inventory

Develop enhanced wetland inventory of parklands
Develop a park-wide high resolution enhanced wetlands inventory that will incorporate ground-truthing. The inventory should include characterizations of the physical and biological conditions. Collaborate with U.S. Fish and Wildlife Service on this remapping effort.

Identify groundwater recharge areas for the park
Determine groundwater recharge areas for the park to provide better protection to park groundwater systems.

Create detailed geologic map of the park
Complete detailed geologic maps at 1:24,000 scale with a description of map units. Maps could be adapted from existing surficial geology map and should also include: 1) an inventory of beach ridge and paleoshoreline features, 2) delineate active and forested dune areas, 3) outcrops of paleosols, dating sites, and fossil locations (prairie vole), 4) glacial flow lineations, glacial margins, and 5) integrate subsurface data (combine onshore and offshore data).

Contact
Bruce Heise, NPS Geologic Resources Division; bruce_heise@nps.gov, (303) 969-2017

Acquire stereo aerial photography of parklands
Contract for routine stereo aerial photography of the park to provide a useful long-term monitoring tool to document changes to the park's natural resources. Aerial photography should be flown every 5-10 years or after a major disturbance. Aerial photography may potentially be cost-shared with other agencies such as the county, if flying at a similar time.

Recommendations for monitoring

Conduct reassessment of surface water quality
Complete a park-wide reassessment of surface water quality. Compare results of the water quality assessment to Handy and Stark's (1984) evaluation of water resources of the park, and Boyle and Hoefs (1993) park water resources inventory.

Establish groundwater monitoring program
Develop a baseline groundwater monitoring program for the park. Include monitoring areas adjacent to potential contamination sites. For example, conduct groundwater monitoring downflow of the Schmidt pig farm where septic system effluents are dumped on the open ground surface and near the Homestead Resort where aerial spraying of septic water occurs. Need to estimate bacterial loading and monitor for groundwater contamination. Should also consider surface water monitoring at both sites.

Monitor piezometric network
Work with USGS to continue monitoring piezometer (instrument that measure pore water pressure) networks associated with coastal bluff stability monitoring. Extend monitoring network to other appropriate locations in the park based on recommendations by the USGS.

Contact
Bruce Jaffe, USGS; bjaffe@usgs.gov, (831) 427-4742

Monitor USGS beach profile transects
Survey coastal transects. Since 1989, Bruce Jaffe, USGS, has surveyed nine coastal transects in the park to access coastal change. Beach profile surveys are currently tied to temporary benchmarks. Establish permanent monuments for coastal transects that are located with GPS and tied to absolute elevation. Work with Dr. Jaffe to determine a monitoring frequency.

Contact
Bruce Jaffe, USGS; bjaffe@usgs.gov, (831) 427-4742

Expand long-term photo-point monitoring of sensitive areas in the park
Establish photo-points of sensitive areas in the park. GPS location of photo-points. The park has some established photo-points; however, long-term photo-point monitoring can be expanded in the park.

Reference
Hall, Frederick C. 2001. Photo point monitoring handbook: part B – concepts and analysis. Gen. Tech. Rep. PNW-GTR-526. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 86 p. 2 parts.

Hall, Frederick C. 2001. Photo point monitoring handbook: part A – field procedures. Gen. Tech. Rep. PNW-GTR-526. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 48 p. 2 parts.

Acquire Lidar of shoreline areas and dune fields
Contract for Lidar (Light Detection and Ranging) surveys of the shoreline to provide baseline information for long-term monitoring of shoreline stability and dune migration.

Contact
Rebecca Beavers, NPS Geologic Resources Division; rebecca_beavers@nps.gov, (303) 987-6926

John Brock, USGS; jbrock@usgs.gov; (727) 803-8747 x3088

Recommendations for research

Determine paleoecology of the park
Study stratigraphy and pollens in sediment cores from wetlands and lakes to:

- Develop a general picture of plant succession in the Holocene
- Evaluate the relationship between fire and dune stability. Compare results to fire history studies and dune mobility in Canada.
- Determine if the inundation and subsequent death of shoreline forests associated with high lake level stands is a normal sequence.
- Extend sediment coring beyond wetlands and include lakes to establish historical record of climate and ecosystem changes recorded in pollen records. Dune history is intertwined with lake levels. Determine effects of lake level fluctuations on ecosystems in geologic past.

Develop hydrodynamics model
Develop a hydrodynamics model from bathymetry, currents and sediment composition.

Determine distribution of biotic crust
Determine the distribution and extent of biotic crust in the park and the sensitivity to human disturbance (social trails). Evaluate the importance of this type of soil resource and provide guidance to park management.

Contact
Pete Biggam, NPS Geologic Resources Division; pete_biggam@nps.gov, (303) 987-6948

Investigate factors that initiate marl deposition
Marl deposits can be found in some areas and not in other parts of the park. Determine what factors cause marl deposition. Evaluate the effects of marl on local water chemistry.

Evaluate relationship between unvegetated slopes along shoreline and sand accumulations
Determine if the unvegetated slope areas along the shoreline at the Lake Michigan Overlook lead to additional sand accumulation on adjacent dunes. Potentially use surface cover (% pebble cover) to evaluate the sediment composition change.

Study tufa formation in the Platte River
Investigate tufa formation in the Platte River near the M22 Bridge. Coatings of tufa a few millimeters thick occur on rocks recently used to stabilize the bank and on the shells of living snails in the river and indicate that tufa must have formed in the past few years. The origin of tufa is unknown, but probably merits further investigation and monitoring because Ca is considered a limiting nutrient to ecosystems and may be an important aspect of the park ecology and resources.

Recommendations for geologic studies to support park management issues

Monitor visitor influence on dune movement at the Dune Climb
Investigate the use of time-lapse video cameras to document human impacts on and movement of the Dune Climb. Establish and survey a transect down the face of the Dune Climb. Use videography with marker poles to measure dune movement over a summer season. Evaluate dune movement rates in relation to park visitation numbers (use visitor database from the entrance fees at the Dunce Climb parking lot). Compare dune movement rates at the Dune Climb with adjacent vegetated dune slopes. Monitoring technique may also be applied to the Lake Michigan Overlook.

Update Water Resources Management Plan
Work with the NPS Water Resources Division to update the park's Water Resource Management Plan. The plan is currently in draft form for internal review.

Monitor impacts of social trails
Use sequential aerial photography to evaluate the extent and impact of social trails. Measure linear feet of trails and compare with park visitation numbers over time. May help set use limits in specific areas of the park.

Develop predictive model for coastal bluff landslides
Develop predictive model for coastal bluff landslides using data gathered from piezometer networks.

Contact
Bruce Jaffe, USGS; bjaffe@usgs.gov, (831) 427-4742

Quantify erosion from roads
Identify and quantify erosion from existing county roads in the parks and document impacts to park resources. Identify prescriptions to correct road problems and potential mitigation for road impacts. Consult with the Environmental Protection Agency on the Clean Water Act and point source pollution as a potential tool to address these erosion sources from non-park roads.

Quantify canoe use impacts on bank erosion and riparian vegetation
Evaluate sequential air photos to quantify bank erosion and changes in riparian vegetation on streams impacted by canoe use.

Evaluate long-term coastal response to removal of coastal structures
Use sequential aerial photographs to determine the long-term coastal response to removing old shoreline structures and groins.

Evaluate effects of dredged material on shoreline processes
Study the effects of dredged material on shoreline processes and down drift areas. In particular, focus on the effects of dredging at the mouth of the Platte River and the effects of dredging at the ferry docks on the North and South Manitou Island.

Evaluate impacts of Platte River dredging on stream hydrology and wetlands
Determine impacts of dredging at the mouth of the Platte River on stream hydrology and wetlands during times of high and low lake levels.

Determine resource management issues related to slant drilling
Investigate natural oil and gas assessments in the vicinity of the park to identify and determine resource management issues related to slant drilling.

Map bathymetry and offshore cultural resources
Develop maps of bathymetry and offshore cultural resources (especially shipwrecks). Investigate the use of side scan radar and seismic data.

Contact
Rebecca Beavers, NPS Geologic Resources Division; rebecca_beavers@nps.gov, (303) 987-6926

List of Participants

Sleeping Bear Dunes National Lakeshore
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Appendix A: Descriptions of 27 Geoindicators

Appendix B: Human Influences

Appendix C: Introducing Geoindicators

Appendix D: Species Don't Stand Alone—Geology's Role in Ecosystems

Appendix E: Park Geological Setting

Appendix F: Park Setting

Appendix G: Compilation of notes taken during Scoping Session

Appendix E: Park Geological Setting

By Scott Lundstrom

Bedrock

Bedrock subcrop that underlies the area of Sleeping Bear Dunes National Lakeshore (SLBE) is shown on Milstein (1987) as the Devonian Traverse Group with a fringe of overlying Antrim Shale along the southeastern margin of the area. The strata dip gently southeastward into the Michigan Basin (a Paleozoic bedrock structural basin centered on the southern peninsula of Michigan, and not to be confused with the Lake Michigan basin). The fossiliferous limestones of the Traverse Group includes reef limestones with Hexagonaria coral, of which the famous Petoskey stones of this region are composed. However, Petoskey stones and a great variety of other Paleozoic and Precambrian rock types that make up the gravel in the much younger Quaternary deposits of the region were rounded and polished during transport by glaciers, rivers, and by wave action on beaches, as described below. The bedrock is generally buried at SLBE by as much as 600 feet of Quaternary deposits.

Quaternary Deposits

The Quaternary stratigraphy which dominates the landforms and thick surficial materials of SLBE, consists of Pleistocene glacial deposits of a continental ice sheet, and postglacial Holocene materials deposited by a variety of surficial processes associated with lakeshores, wind, rivers, and hillslopes. Glacial forms constitute the largest elements and main relief of the landscape. The associated glacial deposits compose the bulk of the materials underlying the landscape, but were then modified and reworked by lakes, streams and wind in postglacial time. Earth's climate history of the past 1 million years or so is dominated by a cyclicity of many glaciations separated by interglaciations like the one in which we presently live and have developed our modern civilization. However, the glaciated landscape of the SLBE region was developed mainly near the end of the last glacial advance onto the lower Peninsula of Michigan during latest Pleistocene time.

Late Pleistocene Glaciation

We infer from dated buried peats that at least some of lower Michigan was ice free about 35,000 years ago, but by about 24,000 years ago at the last glacial maximum, the Laurentide ice sheet, which covered most of Canada, had extended south across all of Michigan to a latitude of about 40 degrees N across central Indiana, Illinois, and Ohio. At this time, the SLBE area, as in the rest of Michigan, was under several thousand feet of ice and the glacial deposits probably consisted of little more than a thin discontinuous basal till over bedrock at the base of the glacier. Most glacial deposits and landforms were deposited near the glacial margin. North of the last glacial maximum margin, there are numerous moraines marking stillstands and minor readvances in the general northward retreat of the ice margin. Even by about 14,000 years ago, the entire area of present lake Michigan and most of Michigan were still occupied by an active glacier that formed probably coeval elements of the Valparaiso and Lake Border moraines

(Lundstrom et al, 2001). However, by about 12,000 to 13,000 years ago, all of the lake and lower peninsula of Michigan were ice free as shown by the dated buried forest at Two Creeks Wisconsin and by the Cheboygan bryophyte bed near the Mackinaw Straits. As far as I know, Twocreekan peat or other organic deposits have not been found and dated in the SLBE area. It is likely that this area was vegetated then, and remnant organic materials should have been buried by deposits of the next glacial advance, if they were not totally destroyed by it. If such glacially buried organic materials are known or discovered at SLBE, they would be of great scientific value (and I would like to be notified).

Greatlakean Advance

The latest glacial advance onto the southern peninsula of Michigan occurred after the Twocreekan interstade as shown by glacial till which overlies the Cheboygan bryophyte bed and the forest bed at Two Creeks. The time of this last glacial advance is called the Greatlakean substage. A band of uplands and ice contact features known as the Manistee moraine extends north near the lakeshore from Manistee into this area and was correlated to the Greatlakean substage by Evenson (1973). This glacial advance is not well understood as indicated by its scanty and contradictory coverage in the existing literature. The prevailing paradigm (Farrand and others, 1984, Wallbom and Larson, 1999) is that Greatlakean ice only extended as glacial fingers into embayments into the pre-existing glacial headland but left no prominent end moraines. These embayments are now occupied by Glen Lake, Empire, and Platte Lake, as well as by Lake Lelanau and the arms of Grand Traverse Bay. In this paradigm, the deposits that form the pre-existing glacial headland were formed prior to the last advance.

The latest glacial advance and its deglaciation is interpreted herein to be associated with the major suite of glacial landforms and deposits of the area. There are two types of terrain associated with the advance – terrain formed in front of the glacier (proglacial), and that formed beneath it (subglacial). The most extensive landform type in the region, though only a small part of SLBE park area, is the proglacial pitted outwash plain. It includes most of the area traversed by highway M-72 between Traverse City and Empire, and occurs within the park in two areas: one is in the SLBE outlier (that includes Bow Lake) southeast of Burdickville; and the other is the area just north of the park boundary at Empire within the north halves of sections 15 and 16 and northeastern section 17 in Empire Township. The outwash deposit is composed of stratified and sorted sand and gravel that represents an aggradational deposit of a large discharge of meltwater and sediment at and beyond the ice sheet margin at that time. The surface of the deposit forms a plain that slopes gently southward from just above 300 m (about 1000') altitude where it contacted the ice margin south of Glen Lake (within the above-mentioned areas) to the proglacial lake Chicago level to which it grades near Manistee. The plain is 20-40 km wide and formed between the ice margin about 10 km inland of the present Lake Michigan shore and the upland to the east which was formed at an earlier ice margin. This plain is interrupted by numerous closed depressions called kettles, of which some but not all contain lakes. The depressions were formed when blocks of ice were buried by sand and gravel outwash, then the ice melted and formed a void after sand and gravel deposition ceased. The Park outlier that includes Bow Lake is oriented over an elongate N-S trending set of closed depressions, and illustrates the typically complex collapsed kettle topography formed by ice blocks buried in outwash. The uncollapsed high rim of the outwash plain surface forms the rim of this kettled area within this park outlier. The north and west margins of the outwash plain approximate the glacial margin and occur within the park as north- and west-facing scarps in sections 15, 16, and 17 in Empire Twp.

Though the area of the outwash plain within the park is relatively small, the outwash deposit has a greater significance to the hydrology and ecology of the area and park resources through its influence on the quality and quantity of linked ground water and surface water resources. Because this upland deposit is composed of permeable sand and gravel, the outwash plain is a main ground-water recharge area and the deposits comprise a principal aquifer of the area. This aquifer discharges to lower wetlands and lakes in the kettles such as in the outlier that includes Bow Lake; to river and stream systems that dissect this aquifer, such as the Platte River with its lower end in the park; and to other wetlands within SLBE north and west of the scarp margins at the head of outwash. Water quality is greatly affected by these relations, and will be discussed in a later section.

Subglacial features form both uplands and lowlands within SLBE to the north and west of the head-of-outwash glacial margin. The glacial deposits that form the uplands south of Empire and southwest, north, and east of Glen Lake are composed largely of stratified sand and gravel similar to that of the above pitted outwash plain, but have a much different surface form. They do not have pitted or planar form. Instead, their ridged form is indicative of subglacial molding by basal sliding and associated subglacial hydraulic systems. There are prominent linear subparallel southeast-trending ridges on these uplands that are good examples of ice molded (drumlinized) topography. Though they are not classical drumlins found elsewhere, they indicate subglacial molding and glacial flow direction, which is generally southeastward in this area. Good examples occur south of Empire and in the area traversed by the Pierce Stocking Drive. Since these forms occur on deposits composed of stratified sand and gravel like outwash, the simplest explanation is that they were first deposited as proglacial outwash which was overridden during the latest advance. This explanation contrasts with that offered by Wallbom and Larson (1999) who interpret at least some of these ridges as crevasse fills. The geometry of clay and silt beds, as well as paleochannels within the stratified sand and gravel strata of which these uplands are composed are significant to the groundwater hydrology, pore pressures, and their relation to landsliding of coastal bluffs on these uplands (Jaffe and others, 1998, 2000).

A separate aspect of the form of these uplands is their relation to adjoining lowlands. Especially prominent in the area northeast of Glen Lake, the ridges are bounded, subdivided, and intermingled with a set of anastamozing valleys. This valley system does not have the form and characteristics of subaerial streams, but was probably eroded into the glacially overridden sand and gravel by a vigorous subglacial hydraulic system. This subglacial hydraulic system supplied the proglacial outwash system discussed above with abundant meltwater and sediment. These subglacially formed tunnel valleys range in width from less than 100 m to several km, such as that now occupied by Glen Lake. These onshore lowland valleys appear to be continuations of large-scale offshore valleys known from bathymetry (Holcombe and others, 1996). However, coastal and eolian processes and sedimentation have significantly modified and infilled these subglacially formed valleys along and near the lakeshore, as discussed below.

Both the pitted outwash plain and subglacial features described above relate to the latest glacial advance and its termination in this area, but there are also some noteworthy deglacial features in SLBE. As the subglacial hydraulic system waned and the glacier front receded, it no longer supplied discharge to the outwash plain. Some deposition of similar sediment occurred to form inset (kame) terraces between the glacier and the newly formed scarp at the head of outwash. These terraces occur in the park in sections 9,10, 11 and 14 of Empire Township. Block slumping, shore erosion, and fluvial processes may also have contributed to the formation of these terraces and north-facing scarps. A large glaciofluvial system was then superimposed on these kame terraces as evidenced by incised fluvial meanders that occur just east of Empire – they are depicted as a glacial drainage channel on the geologic map figure of NPS, 1998. This channel could only have developed in this position by being confined between the head of outwash and stagnant glacial ice that occupied the lowlands that now contain Empire, Glen Lake, and Platte Lake. Moreover, the incised nature of the channel indicates a sediment-poor meltwater system from the stagnant ice sheet, in marked contrast to the earlier sediment-rich outwash system. Similar features occur elsewhere near Lake Michigan (Lundstrom and others, 2001), but the incised meander near Empire is remarkable.

The stagnant ice sheet in the northern Lake Michigan basin probably disintegrated and retreated rapidly northward as a calving front developed along a lake at its margin. The large proglacial lake developed into glacial Lake Algonquin, which was the cause of many high erosional shoreline scarps in northern Michigan. It may be the erosional source for some of the high scarps found in and near SLBE north and west of the head of outwash. The west facing scarps that appear to be superimposed on the banks of the above-described erosional channel in sections 17, 19, and 20 of Empire township might be Algonquin shore features or they may only be fluvial scarps cut during the evolution and incision of the paleochannel.

Postglacial (Holocene) Processes and Record

Lake level history and shoreline processes

There have been three major controls on the level of lake Michigan in postglacial time: changing outlets, isostatic rebound, and climate. Glacial recession uncovered lowlands on the east side of Lake Huron at North Bay, Ontario while the crust was still isostatically depressed from the weight of the ice sheet and had not yet rebounded. This caused the upper Great lakes levels to be lowered about 8000 to 9000 years ago to levels much below that of Lake Algonquin – Lake Michigan was lowered to a level about 90 m below present (Lake Chippewa). This caused river systems to incise in response to the lower base levels, as interpreted by Barnhardt and others in offshore stratigraphy north of Glen Lake. As isostatic rebound raised the North Bay outlet, lake levels also rose, and the lakes eventually discharged through southern outlets. This transgression to levels several meters above present is termed the Nipissing transgression, upon which has been superimposed smaller events like influxes of water from Lake Agassiz (Colman and others, 1992). Climate has been the main control on short term variability in lake level in the past 5000 years, with a more steady superposed effect of isostatic rebound that exponentially decreases with time and distance southward (Larsen, 1987).

Shore processes respond to climatically determined lake levels. At high lake levels, storm waves erode and undermine bluffs composed of readily eroded unconsolidated glacial deposits, which in this area are largely composed of sand and gravel. Continued landward erosion at the base of bluffs would increase the angle of slope, but slope processes tend to maintain characteristic angles of about 35-42 degrees on these slopes (Nash, 1980), as long as the slopes continue to be actively undermined by waves. Wave swash and longshore currents transport eroded material both along and offshore (Jaffe and others, 1993) to areas of lower energy , which tend to be the embayments that are relicts of subglacial processes described above. Initial spit growth closed off bays to become lakes such as Platte, Glen, Bass and Little Traverse Lakes. Continued but episodic lakeward accretion of sand into these embayments formed concentric rows of beach ridges during high lake levels (Baedke and Thompson, Thompson and others, 1997) with intervening swales representing lower levels between the highstands that formed each beach ridge. The authors interpret their data to indicate highstand and beach ridge cycles of about 30 and 150 years, and that most beach ridges formed between about 1000 and 2500 years ago.

Dunes: eolian forms, process, and history

Sand dunes accumulate and evolve where there are permissive combinations of sand supply and wind conditions. At SLBE, dunes are generally associated with present or past coastlines, but dune form, distribution, activity, stratigraphy, and history exhibit great variety within the park. Dune form ranges from common parabolic forms (also commonly open to the southwest) to longitudinal, transverse, and foredune ridges, and hybrid forms that defy categorization. Dunes occur in the lowland embayments along Platte Bay, Sleeping Bear Bay, Good Harbor Bay, and Empire, and in perched positions on glacial uplands of Empire Bluffs, Sleeping Bear Plateau, and Pyramid Point. The Manitou Islands also exhibit their own unique combinations of all of the above categories. The active dune field of the Sleeping Bear Plateau grades northward into the lowland at the west end of Glen Lake. The upland dunes include intradunal areas with exposed glacial gravel. Ventifacts occur where gravel is exposed to sandblasting action. Nonvegetated active dunes, including blowouts, are interspersed with sparsely vegetated plant communities that coexist with some level of dune activity, and contrast with dense, mature hardwood forest on inactive dunes. Buried soils exposed by dune activity and coastal erosion indicate that stability and instability of the aeolian landscape vary during recent time.

Loope and Arbogast (2000) applied radiocarbon dating to many paleosols (past soils) that represent forest soils that were buried by dune activity in the SLBE area. The dates span much of the past 5000 years with more than half the dates being less than 1500 years. Moreover, the authors state that a majority of the sand volume of sites in the SLBE area was emplaced above buried soils dated at 1500 calendar year before present or younger. They favor a model in which dune building , whether in perched or lowland positions, occurs at high lake levels and interpret their dates from the length of the eastern shore of Lake Michigan to indicate an approximate 150-year cycle in dune building synchronous with the lake level record of Thompson and others (1997). Increased sediment supply is plausible during shoreline bluff erosion, especially of the large sandy bluffs like that of the SLBE uplands, but so is a greater sediment supply from greater extent of exposed beaches during low lake levels and transitions to them, as we see this year. The relation of dune activity to lake level is complicated because both are related to climate. As hinted at by charcoal being one of the types of dated material, fire history related to climate and human history is also a likely variable in dune history.

Coastal Hillslope Processes: landslides, scarp evolution

Geomorphic processes on hillslopes include landsliding and smaller scale processes like creep, rain splash, and tree throw. Catastrophic landsliding of coastal bluffs at Sleeping Bear Point has occurred in 1995, 1971, and 1914 (Jaffe and others, 1998, Barnhardt), and should be considered an intermittently active process and potential hazard. The 1995 landslide moved approximately 1 million cubic meters of material that included an approximately 500 m section of coast, with slide materials extending to 3-4 km offshore. Barnhardt and others relate the unusually high frequency of landslides restricted to this section of the coast to a paleochannel and unconfomities in the Quaternary stratigraphy that they investigated in the subsurface and beneath the lake by geophysical methods. They further relate the stratigraphy and unconformities to the postglacial lake level history discussed above, though other scenarios to create the unconformities are also possible.

Though smaller-scale, less catastrophic processes such as creep and tree throw are difficult to observe, they are significant and probably more generally applicable to hillslope evolution of paleo-shorelines, and to other scarps and hillslopes produced during the dynamic history discussed above. Nash (1980) investigated the evolution of shoreline scarps of Nipissing, Algonquin, and modern age elsewhere in northwest Michigan and found consistent systematic differences in form, such as maximum scarp angle and curvature that can be explained by a steady-state model, and which could be used to identify age groups of shorelines at SLBE. There are also events of mass slumping that occur all along the bluffs in the park, especially in years of high water levels. These features are very obvious although not as spectacular as the Sleeping Bear Point landslide.

Fluvial processes

Though glaciofluvial processes were of major importance in the glacial deposits and landforms described above, the only modern river in SLBE is the lowest few kilometers of the Platte River between Platte Lake and Lake Michigan. Its course here has a remarkable coincidence with the inflection in the curvature of parallel beach ridges that occur on either side of it, suggesting a relationship between fluvial sediment transport, the location of Platte River point over time, and beach ridge formation.

Another notable feature and process that occurs in this part of the river is tufa precipitation, which will be discussed in the next section.

Hydrology and Water Quality

A good overview of the water resources and hydrology of SLBE is provided by Handy and Stark (1984), but I would like to note a potentially important phenomena that may not be previously described or investigated. In reconnaissance, I observed very young, probably active calcitic ($CaCO_3$) tufa precipitation in the Platte River near the M22 Bridge. Since coatings of this tufa a few mm thick occur on rocks recently used to stabilize the bank and on the shells of living snails in the river, the tufa must have formed in the past few years. The origin of the tufa is unknown, but probably merits further investigation and monitoring because Ca is considered a limiting nutrient to ecosystems and may be an important aspect of the park ecology and resources. A microbiologic origin would not be surprising but precipitation also probably requires supersaturation with respect to $CaCO_3$. The groundwater and surface water resources have relatively high Ca and HCO_3 (Handy and Stark, 1984). It is likely this is related to the abundance of limestone clasts and permeable nature of the glacial deposits, especially the outwash plain that is dissected by most of the length of the Platte River and its tributaries. Groundwater may be acquiring its high values of Ca and HCO_3 by dissolution of limestone clasts in the sand and gravel aquifer. Groundwater discharge is known to be the dominant component of flow of northern Michigan rivers, and that probably is the case for the Platte River. Since snowmelt is a major source of groundwater recharge, groundwater temperatures are cold and coldwater rivers such as the Platte River warm on their way downstream in summer months especially with residence time in shallow lakes like Platte Lake. Calcite is less soluble at warmer temperatures so tufa precipitation is favored in the warmer waters of the lower Platte River in the summer.

References

Baedke, S.J., and Thompson, T.A., 1993, Preliminary report of late Holocene lake-level variation in northern Lake Michigan: Part 1: Indiana Geological Survey Open-file Report 93-4.

Barnhardt, W.A., Jaffe, B.E., Kayen, R.E., 1999, Mitigation of landslide hazards at Sleeping Bear Dunes National Lakeshore, Michigan, (abs.) Geological Society of Abstracts with Programs.

Barnhardt, W.A., Jaffe, B.E., Kayen, R.E., 1999, Evaluation of landslide hazards with ground-penetrating radar, Lake Michigan coast: Coastal Sediments '99, v.2, p. 1153-1165.

Barnhardt, W.A., Jaffe, B.E., Kayen, R.E., and Cochrane, G.R., 2001, Lake-level change and coastal landslides at Sleeping Bear Dunes National Lakeshore, Lake Michigan, USA: Journal of Coastal Research (submitted, in review).

Calver, J.L., 1946, The glacial and post-glacial history of the Platte and Crystal Lake depressions, Benzie County, Michigan: Part II of Occasional Papers on the Geology of Michigan, State of Michigan Department of Conservation, Geological Survey Division Publication #45, Geological Series #, p. 1-70.

Colman, S.M., and 8 others, 1994, Lake-level history of Lake Michigan for the past 12,000 years: the record from deep lacustrine sediments: Journal of Great Lakes Research, v. 20, p. 73-92.

Dorr, J.A., and Eschman, D.F., 1970, Geology of Michigan, University of Michigan Press.

Dow, K.W., 1937, The origin of perched dunes on the Manistee Moraine: Papers of the Michigan Academy of Science, Arts, and Letters, v. 23, p. 427-440.

Dow, K.W., 1940, Some examples of ventifacts from Sleeping Bear Point, Leelanau County, Michigan: Papers of the Michigan Academy of Science, Arts, and Letters, v. 25, p. 473-476.

Farrand, W.R., and Bell, D.L., 1982, Quaternary Geology of Michigan, Michigan Geological Survey Map, scale 1:500,000.

Farrand and others, 1984, Quaternary geologic map of the Lake Superior 4 x 6 degree quadrangle: U.S. Geological Survey Miscellaneous Investigations Series Map I-1420 (NL-16).

Gates, D.M., 1939, A deposit of mammal bones under Sleeping Bear dune: Transactions of the Kansas Academy of Sciences, v. 42, p. 337-338.

Gates, F.C., 1950, The disappearing Sleeping Bear dune: Ecology, v. 31, n. 3, p. 386-92.

Handy, A.H., and Stark, J.R.,1984, Water Resources of Sleeping Bear Dunes National Lakeshore, Michigan, U.S. Geological Survey Water-Resources Investigations Report 83-4253, 39 p.

Holcombe, T.L., and others, 1996, Bathymetry of Lake Michigan, NOAA, World Data Center for Marine geology and geophysics Report MGG-11.

Jaffe, B.E., List, J., Hansen, M., and Hunter, R., 1993, Numerical modeling of shoreline change from longshore transport in the Platte Bay region, Lake Michigan, in List, J. H., ed., Large Scale Coastal Behavior '93, U. S. Geological Survey Open-File Report 93-381, p. 82-85.

Jaffe, B.E., Kayen, R.E., Gibbons, H., Hendley, J.W., Stauffer, P.H., 1998, Popular Beach disappears underwater in huge coastal landslide—Sleeping Bear Dunes, Michigan: U.S. Geological Survey Fact Sheet-020-98.

Jaffe, B. E., Kayen, R. E., Barnhardt, W. A., Reiss, T. E., Cochrane, Guy R., Yancho, S., and Holden, M., 2000, Recent huge landslides in the Sleeping Bear Dunes National Lakeshore, Michigan-- Implications for assessing coastal landslide hazards in the Parks, Geological Society of America Abstracts with Programs.

Kincare, 2000, Reassessment and correlation of Lake Algonquin shorelines in Michigan, abstract in Great Lakes Geological Conference, Michigan Geological Survey Division.

Larsen, C.E., 1987, Geological history of Glacial Lake Algonquin and the upper Great Lakes: U.S. Geological Survey Bulletin 1801, 36 p.

Leverett, F. and Taylor, F.B., 1915. The Pleistocene of Indiana and Michigan and the history of the Great Lakes: U.S. Geological Survey Monograph 53, 529 p.

Loope, W.L., and Arbogast, A.F., 2000, Dominance of an ~150-year cycle of sand-supply change in late Holocene Dune-building along the eastern shore of Lake Michigan: Quaternary Research, v. 54, p. 414-422.

Milstein, R.L., 1987, Sleeping Bear Dunes National Lakeshore, Michigan, in Geological Society of America Centennial Field Guide-North Central Section, p. 303-306.

Milstein, R.L., 1987, Bedrock Geology of Michigan, Michigan Geological Survey Division.

Nash, D., 1980, Forms of bluffs degraded for different lengths of time in Emmet County, Michigan, U.S.A: Earth Surface Processes, v. 5 p. 331-345.

Pruitt, W.O., Jr., 1954, Additional Animal remains from under Sleeping Bear Dune, Leelanau County, Michigan: Papers of the Michigan Academy of Science, Arts, and Letters, v. 39, p. 253-256.

Thompson, T.A., and Baedke, S.J. 1997, Strand-plain evidence for late Holocene lake-level variations in Lake Michigan: Geological Society of America Bulletin, v. 109, p. 666-682.

Walbomm, T. E. and Larson, G.J., 1999, Surficial geology of Sleeping Bear Dunes National Lakeshore, Lake Michigan: a product of the USGS-EDMAP Program: Geological Society of America Abstracts with Programs, v. 31, n. 5, p. A-78.

Waterman, W.G., 1927: Ecology of Glen Lake and Sleeping Bear region: Papers of the Michigan Academy of Science, Arts, and Letters, v. 5, p. 351-375.

U.S. National Park Service, 1998, Sleeping Bear Dunes National Lakeshore: The Story of the Sand Dunes.

Appendix F: Park Setting

Public Law 91-479 dated October 21, 1970 created Sleeping Sear Dunes National Lakeshore. The Act states that, "Congress finds that certain outstanding natural features, including forests, beaches, dune formations, and ancient glacial phenomena, exist along the mainland shore of Lake Michigan and on certain nearby islands in Benzie and Leelanau Counties, Michigan, and that such features ought to be preserved in their natural setting and protected from developments and uses which would destroy the scenic beauty and natural character of the area."

Congress established these outstanding natural features as Sleeping Bear Dunes National Lakeshore, a unit of the National Park Service. To carry out this preservation and protection, Congress requires the Secretary of the Interior to "administer and protect the Sleeping Bear Dunes National Lakeshore in a manner which provides for recreational opportunities consistent with the maximum protection of the natural environment within the area."

There are about 57,000 acres of land within the park (of the 71,000 total acres, which includes water) that include scenic beaches, dunes, beech/maple forests, lakes, streams, and landforms. Massive glaciers that once covered the area followed by the succeeding affects of the melt water from these glaciers and wind erosion has shaped the landforms and features of the park. These landforms include the beaches, moraines, dunes, perched dunes, kettles, truncated headlands, drainage channels, embayment lakes, streams, bogs and springs. Each landform has its own characteristic vegetative cover and wildlife resources.

Special wildlife features in the park include the endangered piping plover that nests on the beaches, threatened bald eagles that pass through the area and currently nest in the park, and the upland sandpiper which is considered a rare species in Michigan, that nests in the open fields. In addition, the park contains loons, ducks and geese that nest in the small lakes and ponds, owls, hawks, badgers, river otters, fox, mink, flying squirrels and many others.

The park contains rare orchids and ferns, a grove of giant white cedar trees, and an array of plants of special interest including the federally listed threatened Pitcher's thistle and endangered Michigan monkey flower. Additionally, there are impacts of former land uses, gravel pits, dumps, and abandoned farm fields, that have impacted the natural environment.

In addition, the park's Statement for Management (1991) clearly sets forth resource management responsibilities as follows:

Natural - To identify, inventory, study, monitor, restore, and protect the natural flora, fauna, geological features, and the natural systems endemic to the area. Take preventive and corrective action for incidents harmful to these resources -such as fires not identified as "allowable" in fire management plans, establishment of an alien species, or spills of hazardous material. Participate in regional programs with neighboring agencies that share in the responsibilities for these resources to ensure that efficient, effective preservation programs are in place. Where consumptive uses are mandated, ensure that resource bases are not harmed.

Appendix G: Compilation of notes taken during Scoping Session

Glacial and Periglacial Geoindicators

Frozen ground activity – Cryogenic depositional phenomena and ice foot/ice cone

Unlike permafrost areas where there is extensive seasonal freezing and thawing of the soil, the majority of the soil in the park doesn't freeze during winter months. However, an unusual phenomena of sand/snow layering occurs during the winter season. Unlike dunes in arid regions, park staff has observed that most sand transport occurs during the winter. Winter winds blow sand and snow in the dunes and cause movement of sand resulting in layered deposits of sand and snow in the coastal bluff areas. This depositional process for the most part is undescribed and for lack of an established terminology, will be referred to as a cryogenic depositional process. In the park, this phenomena is best observed during the winter at the Lake Michigan Overlook. Ice and snow mixed with sand has also been known to cause avalanches.

During the winter an ice foot also forms along the shallow edge of Lake Michigan and can extend out into the lake up to a quarter-mile as a solid sheet of ice. The ice is sheer on the open water-side but protects the beaches and base of the dune slopes from wave erosion. Ice cones can also form as pyramid shaped ice blocks along the shoreline. A general impression by park staff is that winter waves and wind move unprotected sand out into the lakes and during the summer material is tranported back to the shore.

Ice movement is also a significant process in the inland lakes. During the spring thaw, wind moves large ice sheets on inland lakes and creates soil berms or soil ridges along the shoreline. For several years it had been the practice of park staff to remove the soil berm created by the ice at the shoreline of the Little Glen Lake Picnic Site to provide a more manicured beach for park visitors. This same site also had a problem with high E. coli levels in the lake that were for the most part attributed to the feces of waterfowl which were attracted to the adjacent lawn. It was speculated that during rain events surface water flow over the lawn would carry the feces and E. coli into the lake. The park changed management of the picnic area due to the surface water quality issues and left the ice created berms to contain and prevent the E. coli from easily washing into the lake (see surface water quality geoindicator for a detailed discussion).

Cryogenic depositional processes are primarily natural and human influence is low. The main impact to the park is the annual clearing of walkways near the Lake Michigan Overlook following winter sand transport and sloughing of sand from cutbanks. As a result, significance to park management is low.

Aeolian Geoindicators

Wind erosion and deposition

Dune sand is transported by aeolian (wind) processes. Wind creates both constructive and destructive process that can lead to changes in dunes. Movement of sand is important to some plant species in the park. The survival of federally threatened Pitcher's thistle (*Cirsium pitcheri*) requires accumulating sand to thrive and if severed from a sand source the plant communities will not thrive.

In the park, wind causes armoring of the dredge spoils deposited adjacent to the mouth of the Platte River and has also been observed along the shore at the Lake Michigan Overlook. At North Bar Lake, loss of dune vegetation from trampling by park visitors has caused extensive wind erosion of the sand dunes. The park has to mitigate for the loss of vegetation by placing sand fences (similar to snow fences) in the dune field to trap sand and stabilize the dunes. Cord mats on trails and fences to guide visitors have also been installed to keep visitors on trails and to discourage social trails.

The ecological significance of wind erosion and deposition is high. Human influence on accelerating wind erosion of dunes is considered high in the park. Due to human activities, the park expends resources to mitigate for the destabilized dunes.

Dune formation and reactivation

Coastal dunes are important determinants of coastal stability, supplying, storing and receiving sand blown from adjacent beaches. Moving dunes can engulf houses, facilities, developments and road systems. Dunes play an important role in many ecosystems by providing morphological and hydrological controls on biological gradients. Dunes develop under a range of climatic and environmental controls, including wind speed and direction, moisture, and sediment availability. In the case of coastal dunes, like those found at SLBE, lake-level change and beach and nearshore conditions are important factors.

Research by Loope and Arbogast (2000) suggest that in the modern dune landscape found at SLBE and along the eastern shoreline of Lake Michigan is dominated by a dune system that formed during cyclic lake high stands (150-year cycle) over the past 1500 years. Buried soils, while not common, indicate that the sand supply nourishing the dunes have changed dramatically and episodically in the past couple thousand years. The approximate dates of soil burial by dunes roughly correlates with many lake high stands, and Late Holocene lake-level curves for Lake Michigan indicate high stands occur on an approximate 150-year cycle. During the intervening periods of lower lake levels, the relatively low sand supply allowed for establishment of forests and soil development. In the park, future vegetation succession and forest extent will be influenced by changing lake levels and episodes of dune building.

Coastal dunes occur along Platte Bay, Sleeping Bear Bay, Good Harbor Bay and Empire. Dunes are also present on the Manitou Islands. Perched dunes occur at Empire Bluffs, Sleeping Bear Plateau and Pyramid Point and are a relatively thin blanket of sand that have been blown to the top of thick deposit of glacial deposits and create high (300-400 ft) sand dunes. The Dune Climb has evolved from a perched dune that has migrated off the plateau onto the adjacent lowland.

Several prominent dunes in the park include: Sleeping Bear Dune, Empire Bluff Dunes, Pyramid Point Dunes, Lake Michigan Overlook, South Manitou Island and the Dune Climb. Social trails occur throughout the park and many are associated with these dunes. Foot traffic can destabilize dune vegetation and alter sand supply to biotic systems in the dunes.

Human impacts on dune formation and remobilization is variable in the park. On South and North Manitou island human influence on dune stability is low and protection and maintenance of the natural settings on the offshore islands is extremely important. However, popular visitor sites in the park, such as the Dune Climb and Lake Michigan Overlook, are highly modified by foot traffic and social trails. Long-term impacts in areas of high park visitation need to be evaluated (Dune Climb and Lake Michigan Overlook).

Desert Crusts - Biotic crust

A biotic crust is composed of a surface layer of moss, fungus, or lichen that knits together the top layers of soil/sand and protects it from wind erosion. The biotic crust is high in nitrogen, can locally change soil chemistry, and is analogous to crypto-biotic soils on the Colorado Plateau. However, more is known about crypto-biotic soils and this type of biotic crust found at SLBE is not well understood. Like crypto-biotic soils, biotic crusts can be easily disturbed and does not recover quickly. Social trails and foot traffic can have great impact on this unique soil resource.

Biotic crust is known to occur in the park on upper dune slopes where it drops off into Lake Michigan and it has been found in similar locations at Pictured Rocks National Lakeshore. The distribution and extent of biotic crust in the park, sensitivity to human impacts, and the significance of the crust as a soil armoring agent is unknown. Further study is needed to evaluate the importance of this type of soil resource and help provide guidance to management.

The ecological importance of this geoindicator is thought to be high, but since little is known about biotic crusts in the park, the human influence and management significance was rated as unknown.

Groundwater Geoindicators

Groundwater quality

Groundwater is important for human consumption and use, and changes in quality can have serious consequences. It also influences ecosystem health and function. Groundwater is important to the support of terrestrial and aquatic habitat and for maintaining the quality of base flow in rivers and springs. It is critical to detect changes in groundwater quality from both natural and human caused sources (pollution). In the park, the ecological significance of groundwater quality is extremely high due to the interconnection of springs to surface water and lakes in glacial deposits.

There are multiple sources of groundwater contamination in and adjacent to the park. Potential groundwater and surface water contamination sites in the park include but are not limited to:

- A pig farm interior to the park is the site of nearly continuous surface septic sewage disposal.
- A private development adjacent to the park, the Homestead Resort, has an above ground aerial sewage disposal system which discharges on park property.
- Glen Arbor town dump was located in a wetland. The park has removed surface trash. Some toxicity tests have been conducted; however, it is unknown what is buried subsurface in the dump.
- In mid-1970's, the park buried three, five-gallon cans of DDT in the south Manitou Island dump. The park has been unable to locate and remove the drums.
- Trash disposal had taken place on both the North and South Manitou Islands. In the early 1990's, high background levels of arsenic were detected in groundwater monitoring wells on North Manitou Island while investigating an oil spill.
- Park has removed approximately 50 underground storage tanks that have ranged in size from small residential tanks to commercial sites. Some underground tanks still exist in the park and there is a potential for undiscovered tanks to become "ghosts in the closet" and an issue to the park. A former canoe livery located on Highway M-22 and the Platte River was found to have leaking underground storage tanks in the floodplain adjacent to the river. It is also suspected that some old tanks associated with abandoned gas stations or residential sites inherited by the park were never pulled. There were several former gas station sites located in the park, and there are no records to confirm that any of the associated tanks at these sites were ever removed.

Future development of private lands outside the park that are recharge areas for the park's groundwater is a concern. Based on the geologic and hydrologic setting, the upland outwash plain located to the east of the park may be providing recharge to the park's groundwater system. Ground water recharge areas to the park should be identified and groundwater monitoring adjacent to potential contamination sites established.

The park is within the Michigan Basin which contains numerous geological formations that produce oil and gas. Examples of these include the Antrim Shale and Niagaran formations that exist under the park and adjacent areas of Lake Michigan and provide the potential for natural gas/oil development in the area. The park's jurisdiction extends one-quarter mile offshore into Lake Michigan, but the park does not own mineral rights under Lake Michigan or for the majority of the land it owns. A Federal ban is currently in place to prohibit slant drilling under Lake Michigan, with Federal legislation pending to permanently prohibit that activity. There is heavy pressure from the former Governor of Michigan and oil/gas interests to allow for slant drilling under the Great Lakes throughout Michigan.

Human influence on the groundwater quality in the park is high. Due to the high potential for groundwater contamination from multiple sources in the park, this geoindicator also has a high management significance.

Groundwater level

Groundwater is a major source of water in many regions. In the USA, more than half the drinking water comes from the subsurface, and in arid regions, it is generally the only source of water. The availability of clean water is of fundamental importance to the sustainability of life. It is essential to know how long the resource will last and determine recharge rates. While natural changes in groundwater level can be due to climate change (drought, pluvial episodes), the predominate changes are due to human extraction.

Extraction of groundwater occurs in and adjacent to the park and includes:

- The Michigan Department of Natural Resources operates a fish harvest weir on the lower Platte River and can pump 2000 gallons/minute of cold groundwater into the river to attract returning salmon into their weir. The impact of this groundwater extraction is unknown. The cone of depression created by this groundwater pumping has an unknown effect on the adjacent aquatic resources. The park has not monitored the effects of pumping since this activity occurs on DNR property.
- The Village of Empire withdraws groundwater adjacent to the park and stores it in a large underground tank located on park property, just south of town.

Natural changes in the water level of Lake Michigan affects the elevation of the groundwater table in the park. In 1986, a high lake level stand elevated groundwater levels and inundated inland forests resulting in tree die-off and associated wind-throw of pine forests in some areas of the park. The park has no control over these types of natural groundwater fluctuation.

At this time, there is no widespread extraction of groundwater and effects are localized in the park. Human influence on the geoindicator is considered to be low to moderate. However, it is important to establish baseline data to track long-term changes in both water level and quality.

Surface Water Geoindicators

Surface water quality

Clean water is essential to human survival as well as to aquatic life. Pathogens such as bacteria, viruses and parasites can make polluted waters among the world's most dangerous environmental problems. Water quality data are essential for implementation of responsible water quality management, for characterizing and remediating contamination, and for the protection of the health of humans and aquatic organisms.

In general, Lake Michigan has high water quality. However, there are many potential sources of contaminants from human activities that can compromise existing water quality. Offshore between the Manitou Islands and the park mainland is the Manitou Passage, a high use shipping lane. Park aquatic resources have been impacted from the offshore shipping lanes and have documented oil spills and human waste disposal and contamination from freighters. In one incident, a ferryboat docked at South Manitou Island was surrounded by a slick of human sewage that was released from a freighter. The sewage contaminated the island shorelines and aquatic environment. The park is also concerned with medical waste discharged from foreign vessels and the potential contamination from blood born pathogens. There are 58 known shipwrecks in the Manitou Passage Underwater Preserve. Some of these shipwrecks still pose an environmental threat. For example, the Francisco Morazan, a Liberian freighter that washed onto the near-shore shoals of South Manitou Island in 1960, is still an occasional source of oil balls that wash onto the adjacent shoreline.

Infestation and establishment of zebra mussels, an invasive non-native species, have been associated with changes in biotic communities and ecosystems. Zebra mussels have well established colonies along the Lake Michigan shoreline, and have formed five-inch thick mats on the lake bottom near the mouth of the Platte River. The mussels can disrupt aquatic ecosystems by displacing native species. Zebra mussels are suspected of causing certain blue-green algae, cladophora algae blooms, nutrification, and possibly contamination of the swash zone. A visible change is easily observed in the benthic structure of Lake Michigan from a "moonscape" of rocks and boulders to one dominated by zebra mussel and cladophora algae mats.

Swimmer's itch is an intense skin reaction to a burrowing larval form of a flatworm called a schistosome. The larvae are small, about 1/50 of an inch long. These flatworms are parasites of certain snails and warm-blooded creatures such as certain waterfowl and rodents. Even though larval flatworms are not a human parasite, they do burrow into human skin seeking to complete their life cycle. Since humans are not the proper hosts, the larvae soon die. The itch is caused by the body's allergic reaction to the dead larvae under the skin. In past years, the Glen Lake Association has treated that lake with copper sulfate to kill freshwater snails that provide one part of schistosome life cycle. Most lake associations have discontinued the use of copper sulfate, due to residual, detrimental effects. The current control methods focus on the control of waterfowl that carry parasite eggs. The park does not attempt to control swimmer's itch in any of their lakes. Little Glen Lake is usually the only location in the park where complaints relating to swimmer's itch occur.

The managed lawn near the Little Glen Lake picnic area is a major attraction for geese and swans. The feces of these waterfowl appears to be a major contributor to high E. coli levels found in the near-shore waters used by park visitors to that location. The park has taken a number of management actions to decrease the E. coli levels at this location. In the spring, when the surface ice sheet begins to melt, the entire sheet becomes wind driven. This ice movement on the lake creates small soil berms along the shoreline of the lake. In the past, park maintenance staff raked out these ice-formed berms at the Little Glen Lake picnic area to provide a more manicured beach for park visitors. It was speculated that rain events caused surface runoff over the lawn, carrying the feces and E. coli into the lake. It was suggested that the park leave the soil berms intact and allow them to act as a coffer dam to prevent E. coli from easily washing into the lake. The first year after the berm and shoreline vegetation was allowed to remain the E. coli numbers in the lake dropped significantly. At this time, the park also established a 20-foot wide green belt around the lake shoreline. This vegetative strip was used to discourage waterfowl from using the area immediately adjacent to the lake and acts as a filter for overland surface water flow. The park also utilized "cracker shells", loud noise-makers fired from a gun, to discourage waterfowl from utilizing this site. The cracker shells were used to scare waterfowl from the beach when visitors are not present. Education of park visitors to not feed and attract waterfowl to the picnic area and to keep their pets away from the shoreline was also a part of the management strategy to lower E. coli contamination at this site. As a result of the management of this site, E. coli contamination of the lake has significantly diminished.

The salmon hatchery on the Platte River is a water quality concern. Salmon are not native to park streams. Each year thousands of salmon return not only to the Platte River, but to all park streams to spawn and then die. Salmon carcass can add significant quantities of phosphorus to the streams. The Platte Lake Improvement Association has requested that each dead salmon in the Platte River be considered as a point-source of pollution. The salmon, by their sheer numbers impact the stream ecosystems. In addition, the salmon attract recreational fishermen that cause impacts to park streams by their physical contact/trampling of aquatic and riparian vegetation and associated ecosystems.

Sea lamprey are an exotic species that have been responsible for decimating certain fish species in the Great Lakes. The U.S. Fish and Wildlife Service treats park streams with a lampricide, known as TFM (3-trifluoromethyl-4-nitrophenol) to kill juvenile lamprey approximately every three years.

Marl deposition (calcium carbonate deposit) is a widespread natural phenomena. It is hypothesized that calcium carbonate deposition is driven by the change in water temperature from groundwater to surface water. Marl formation in Platte Lake has been identified as a result of carbonate chemistry (calcium carbonate, carbon dioxide, and pH). In a letter to the court, concerning Platte Lake, the Court Master notes that although phosphorus does not directly cause marl to precipitate, it does stimulate algal production. Increased biological production affects carbon dioxide levels in the lake, which in turn directly affects the carbonate chemistry. Marl deposition may affect water chemistry but little is know about it in the park. In the Platte River, calcium carbonate charged groundwater mixes with warm river water and forms tufa dams. At times, Platte Lake will turn white as calcium carbonate precipitates out.

Other sources of pollution include airborne deposition of acid rain, but it is not considered a serious problem due to the ability of soils to buffer the acid rain. Groundwater contaminants leaking into surface water and nitrates from pig farm runoff are other concerns (see discussion of groundwater quality geoindicator).

Uncontaminated surface water is essential to ecosystems and at SLBE it has a high ecological importance. Due to the multitude of human activities that affect water quality in SLBE, human influence and management significance are both considered high.

Streamflow

Streamflow directly reflects climatic variation. Stream systems play a key role in the regulation and maintenance of biodiversity. Changes in streams and streamflow are indicators in basin dynamics and land use. One estimate puts the total annual losses to the economy from flooding of river and coastal plains worldwide at 20,000 million dollars. It is estimated that about ¾ of the total water flow of the 139 largest river systems in North America, Europe and the former Soviet Union is significantly affected by dams, reservoirs, irrigation, and diversions for use outside of the watershed.

There are four streams in the park: the Platte River, Crystal River, Otter Creek and Shalda Creek. The streams are lake or spring fed and are low gradient (very close to base level).

Current human influences on streamflow in the park include:

- A dam on the Crystal River is mandated by court order and used to regulate lake levels in Glen Lake.
- The Platte River Lower Harvest Weir, operated by the Michigan DNR pumps groundwater into the Platte River to augment stream temperature and flow. This assists in the fall harvest of coho and king salmon from the river.

- Dredging the mouth of the Platte River causes increased velocities and in the past has caused up to a two-foot temporary drop in water level one-quarter mile upstream of the mouth

The ecological significance is considered moderate. Since human influence on streamflow is episodic and at this time hasn't resulted in permanent or long-term changes to river hydrology, it is considered moderate in significance. At this time the management significance is moderate.

Stream channel morphology

Channel morphology is a reflection of the underlying geology, and is shaped by the magnitude of water and sediment discharges. In the absence of streamflow records, an understanding of stream morphology can help delineate environmental changes of many kinds. Changes in stream pattern, which can be very rapid in arid and semi-arid areas, can identify places to limit land use, such as on islands in braided streams and meanders bends, or along eroding banks. Significant changes in stream dimensions, discharge and pattern may reflect human influences such as water diversions, increased sediment loads resulting from land clearance, farming or timber harvesting.

Identified human influences on channel pattern in the park include:

- Annual dredging at the mouth of Platte River. (see shoreline position geoindicator discussion on dredging of the Platte River)
- Park removal of hardened structures (bank protection) along streambanks.
- Prior to establishment of the park, owners of streamside residences within the park typically increased their lot sizes by extending the stream banks of their property 10 to15 feet and adding retaining wall. This activity has confined the channel. Many private residences also have docks.
- People create canoe routes through wetlands within the Platte River and alter streambanks at canoe takeouts.
- Non-native spawning salmon can locally modifying the channel bed.
- A dam exists on the Crystal River and the Michigan DNR has a fish harvest weir on the lower Platte River within the park boundary.

Most of the streams in the park are unmodified, except by beaver populations and are relatively stable.

Stream sediment storage and load

Sediment loads determines the shape and pattern of stream channels. Changes in sediment yield reflect changes in basin conditions, including climate, soils, erosion rates, vegetation, topography and land use. Fluctuations in sediment discharge affect many terrestrial and coastal processes, including ecosystem responses, because nutrients are transported together with the sediment load.

In general, streams in the park are low gradient, close to base level, and relatively stable. There is some turbidity in streams after rainfall events. However, the creeks are lake or spring fed and result in low sediment transport. Rivers are also buffered by a series of wetlands and lakes in the river system. An assessment of stream macro invertebrates completed by Boyle (1993) indicated that there is a good diversity of invertebrates and provides a baseline for long-term monitoring of biotic changes due to changes in sediment load, contaminates, nutrient loading, or channel storage.

Dredging upstream and at the mouth of the Platte River for navigation affects sediment storage in the river. However, it is believed that sediment build up at the Platte River mouth is from coastal processes.

Logging activities associated with a 100-year old sawmill on Otter Creek has left a lot of logging slash in the watershed upstream of site. The park wants to rehabilitate impacted sites within the watershed.

Wetlands extent, structure, and hydrology

Wetlands are areas of high biological productivity and diversity. They provide important wildlife and aquatic habitat and are typical sites for human recreation. Wetlands can affect local hydrology by acting as a filter, sequestering and storing heavy metals and other pollutants, serve as flood buffers, and in coastal zones, act as storm defenses and erosion controls.

Wetlands comprise about 20 % of the parklands. The wet and dry seasons cause changes in the size of wetlands. Changing lake levels also affect wetlands. Since the mid-1980's, the water level in Lake Michigan had dropped 50-60 inches. The drop in lake level has caused dewatering of nearshore wetlands. Park personnel observed that in the 1980's they could canoe in wetland areas that are now dry. Within the park a federally listed endangered wetland plant, Michigan monkey flower (Mimulus glabratus), was found at an upland seep near Glen Lake. It is the only known location within the park.

Phragmites australis (common reed) is an invasive exotic species that displaces native species in wetland areas disturbed by humans. Native cattails on Boekeloo Road are being displaced by phragmites. Park staff has observed a significant increase in phragmites in the park, but it is not well documented.

Prior to establishment of the park, it was reported that the Michigan DNR blew holes in the wetlands near Peterson Road with dynamite. This activity could not be verified through contact with the DNR, and if it happened, it took place prior to 1978. This was supposedly done to create habitat for northern pike, which were also supposedly planted there. Although a formal inventory has not been conducted at this location, there is no indication that any of these fish still survive in this area.

Roads can also impact wetland habitat, hydrology, and function. There are public and private roads that cut through and impact wetlands and need to be assessed.

A trip report to Sleeping Bear Dunes by Joel Wagner in July 1998 provides a good discussion of the lack of an adequate wetlands inventory and the effects of Platte River dredging on aquatic resources. Annual dredging at the mouth of the Platte River causes dewatering of adjacent wetlands. Significant affect from dredging can propagate upstream. Past dredging has caused up to a two-foot drop in water level up to one-quarter mile upstream of the mouth. Under natural conditions Wagner (1998) stated that "it is unknown how frequently the river mouth closed, broke open, and migrated at this site but such cycles may range from several times a year in very small systems to once in several years in larger systems."

Wagner (1998) hypothesized that "it is likely that the marshes in the lower Platte River were historically exposed to cycles of rising water after closures (of the river mouth) followed by rapid declines when the river eroded through the barrier again. … Impacts of dredging are more likely to be associated with key biological processes that may be occurring in the lower Platte River and associated marshes in September when dredging and resultant sudden water level declines now occur year after year. An example of such an effect might be a loss of marsh refugia for larval or juvenile fish, which may be flushed into the channel and subjected to excessive predation when dredging occurs." Park staff feel there is a need to evaluate the upstream impacts to stream hydrology and wetlands from dredging on the Platte River during both high and low Lake Michigan levels.

U.S. Fish and Wildlife Service's National Wetlands Inventory program mapped location of wetlands in SLBE, but the maps vary considerably in quality and resolution. The park lacks an adequate inventory and characterization of the parks wetlands that addresses both the physical (classification of habitat) and biological (plant species association, substrate and other factors) aspects of the parks wetlands. The park has a technical assistance request for help inventorying wetlands in the park, but has been notified that this request is beyond the scope of the program. The issue is outlined in the park's draft Water Resource Management Plan.

Wagner (1998) noted that the lack of a high quality inventory map for SLBE can affect the ability of the park to manage and protect park resources by 1) the park cannot protect important wetland resources if they do not know they exist. 2) an enhanced inventory would help direct limited resource management funding toward "hotspot" locations where control efforts would be most effective, and 3) information gathered on park wetlands would focus other park research, resource management, and interpretation efforts.

Lakeshore Geoindicators

Lake level and linkages with relative sea level

The history of fluctuations in lake levels provides a record of climate change on a scale of ten to a million years. Lake level can also be a valuable indicator of near-surface groundwater conditions on the adjacent shoreline (see discussion of drowned forests in previous section on groundwater level) and changes in shoreline position.

In the park, dune formation, groundwater level, and shoreline erosion are all influenced by fluctuations in the level of Lake Michigan and inland lakes. Thompson and Baedke (1997) constructed late holocene hydrographs for Lake Michigan. Their data indicate that there are “quasi-periodic” lake level fluctuations that have two distinct periods and magnitude. A shorter 30-year fluctuation with about a 0.5 m lake level change and a longer ~150 year return period associated with a lake level change of about 1.5 m. Their research suggests that the formation and deposition of beach ridges have formed along Lake Michigan as lake levels rise briefly and then fall. Beach ridges form multi-ridge sequences and may be deposited and are preserved in protected coastal indentations and in areas of positive net sediment supply. In the park, two beach ridge sequences can be observed along the coast from Otter Creek to south of the Platte River.

Lake level records over the past 83 years from the Army Corps of Engineers indicate that variability in lake level is on the order of two meters or more over a 20-30 year period on Lake Michigan. These observations are consistent with the geologic reconstruction of Lake Michigan by Thompson and Baedke (1997).

On inland lakes, beavers dams have blocked the natural outlet of Otter Lake and caused the lake level to rise. The associated rise in water level has flooded the septic system for three private residences. Dams have been bypassed to resolve the problem.

North Bar Lake is an embayment lake that is a fragile area that is impacted by park visitors. Historically, the lake was directly connected to Lake Michigan by an outlet channel. Heavy foot traffic has removed natural vegetation and destabilized the dunes. Increased sand transport from the dunes, in conjunction with low Lake Michigan levels, has caused the outlet channel to be filled in. As a result, the embayment lake is temporarily isolated from Lake Michigan.

The affect of sea level on Lake Michigan is unknown. There are differing viewpoints on the response of the lake to sea level changes and long-term climate change.

Long-term lake level fluctuations significantly influence modern dune and beach ridge formation, and shoreline distribution of forest types. However, human influence on water level in Lake Michigan is low and moderate for inland and embayment lakes. The management significance to the parks is considered to be low.

Shoreline position

The position of shoreline along ocean coasts and around lakes varies over a broad spectrum of time scales in response to shoreline erosion (retreat) or accretion (advance), changes in water level, and land uplift or subsidence. Shoreline position reflects the coastal sediment budget and changes may indicate natural or human-induced effects along shore or in nearby watersheds. The detailed shape and sedimentary character of a beach are highly sensitive to lake influences, including deep-water wave energy, nearshore wave action, storm surge, and nearshore circulation. Changes in shoreline position can affect transportation routes, coastal installations and facilities, communities, and ecosystems.

The park manages about 64 miles of shoreline. Significant shoreline changes have been associated with both natural lake level fluctuations and changes in nearshore sand transport. Future shoreline changes have the potential to affect park infrastructure (piers, boat ramps, buildings). For example, coastline stability related to sand transport can change dramatically from year to year. Historically, the dock at the Coast Guard station on South Manitou Island was periodically destroyed due to mass slumping of underwater sand that build-up around the dock. The last time the Coast Guard rebuilt this dock, the pilings were extended in length to preclude the destruction of this dock by the sand movement.

Future sand transport and shoreline changes may affect the parks underwater cultural resources such as shipwrecks. The effects of sediment transport and shoreline dynamics on shipwrecks is illustrated by the sudden reappearance of the Three Brothers shipwreck. The ship sunk off South Manitou Island early in the century and was buried under sand. The three brothers resurfaced recently in about 15 feet of water when sand shifted, exposing the shipwreck.

Current and potential human induced shoreline changes in the park include:

- Annual dredging of the mouth of the Platte River has occurred over the past 20 years. Dredged sediment is disposed along the coastline adjacent to the mouth of the river. Dredging is provided for fisherman and boater safety and a channel about 2.5 feet deep and 20 feet wide is maintained from the day after Labor Day, for a period of 30 days. The dredged material is composed of coarser sediment than what is naturally deposited along the beach and its effect on the shoreline is unknown. Samples of the dredged material grain size have been assayed at 99+% sand or gravel with fine grains .1% or less. Currently four out of seven pairs of Piping Plovers, a federally endangered species in the park nest in or adjacent to the dredge spoils. Special interest groups continue to press for changes to the mouth of the river which may include pressure for the development of a harbor of refuge or breakwater. However, the parks current practice of annual dredging continues to be the action of least environmental impact.
- Sand movement along the shoreline of North and South Manitou islands affects the stability of docks. Dredging provides access for ferries to the docks on both islands. Dredged material is placed along the shoreline of the islands as

nourishment; however, disposal material is a different texture and composition than beach sediments.

- In the past, a resident living adjacent to the outlet of North Bar Lake requested the park move the outlet further north due to erosion that was occurring along and adjacent to his property. He applied for a dredging permit, but since he did not own the property where the changes would be make, the Michigan Department of Environmental Quality denied the request. Potential future dredging may occur at the outlet of North Bar Lake to restore form and function to the dune/aquatic dynamics at that location. Lake Michigan water levels may play a large role in this system, and the park will wait for higher water levels again before proposing any actions.

Human Influence is considered moderate in some places and high in others, but a significant portion of the park budget (about 5% of a 3 million dollar budget) is spent on addressing issues related to shoreline changes (primarily dredging activities). Therefore, management significance is considered high.

Soil Geoindicators

Soil and sediment erosion

Soil erosion is an important social and economic problem and an essential factor in assessing ecosystem health and function. Erosion of sediment is a natural process that can be strongly influenced (generally increased) by human activities (ie. land clearing, agriculture, road building, etc) within a watershed. Identifying soils sensitive to disturbance will enable better land management decisions and potentially reducing the adverse effects of accelerated soil erosion.

Human influence on the Dune Climb site is high. Each year, many of the 1.3 million visitors to Sleeping Bear Dunes go to ascend or clamber up the dune at the Dune Climb. During the summer, about 3,500 people per day visit the dune climb. Visitors climbing the steep 300-foot sand dune cause downslope displacement of sand and foot traffic does not allow for establishment of vegetation. The park has estimated that the dune moves on average about 3 feet per year. Adjacent dune slopes that are not in direct line with the Dune Climb parking lot are vegetated and stable. Impacts from foot traffic on erosion of dune faces are also an issue at the Lake Michigan Overlook.

Past recreational activities in the park affected erosion and sedimentation processes. In the past, dune skiing using snow skis was an occasional summer activity at the Lake Michigan Overlook that impacted the dune face and caused erosion. This activity was discontinued in the early 1980's. Also, in the late 1970's, the Little Glen Lake was used as a swimming beach, and in an effort to improve the lake for swimming, sand was spread on the winter ice, and allowed to settle on the muck bottom. This sand was removed from dune areas, where it had blown over walkways and improvements.

Channel bank erosion along Platte River is locally accelerated at canoe takeouts. Canoe and inner tube use along the Crystal River has doubled in the last three years. Potential impacts from these recreational activities on bank erosion and removing riparian vegetation are an issue to the park and should be monitored.

There are eleven major sites in the park that were former gravel and sand extraction pits or topsoil mining operations. The largest site covers approximately 65 acres, and was at one time used to mine topsoil (Stanz site). The Stanz site and several topsoil mining sites along the Stocking Scenic Drive collectively cover approximately 40 acres. Two former gravel pits in the park has been rehabilitated completely, and two others are nearly completed. This work started in the late 1970's and is on-going. The average site usually involves movement configuration of 3,000 to 5,000 cubic yards of soil. Gravel from restoration and removal of house sites in the park has been used to reclaim these gravel pit sites.

Erosion on county roads within the parks is a contentious issue. The local counties (Benzie and Leelanau) are paid by the state for each mile of road they maintain. Currently, each county has several miles of right-of-ways in the park, including many on South Manitou Island. Shauger Hill Road is a very steep county road interior to the park with visible gully and surface erosion. Leelanau County is responsible for road maintenance on that particular road. On the S. Manitou Island, Leelanau County is interested in opening right of ways as trails, especially along the western shoreline of Lake Florence, even though a road already exists about a quarter-mile inland that provides access across the island. The park needs to quantify erosion from existing county roads in the parks and document damage to park resources.

In the past, during storm events on Lake Michigan, the flow from Otter Creek was blocked off due to sand deposition at the mouth. As a result, the creek would backup and create a considerable reservoir of water. When the water was eventually breached the sand plug at the mouth of the creek, it would flush violently into Lake Michigan. South Aral Road crosses the creek a short distance upstream of the mouth, and at one time, the creek flowed through several small culverts under the gravel road. When the creek breached the sand plug, stream discharge exceeded the culvert capacity and the entire road crossing would be washed out, including the culverts. In one year the county road failed and was rebuilt several times until larger culverts were installed. Large volumes of gravel were deposited in the downstream reached of Otter Creek as a result of this road management.

Social trails occur throughout the park and can impact aesthetic views in the park and cause localized erosion. The social trails change overtime. However, there has been little documentation of damage associated with social trails. At two locations in the park (near the D.H. Day Group campsites located at the end of Harwood Road north of the Dune Climb, and on South Manitou Island on the trail to the dunes from the Bone Boat), social trails up the dune faces can be found that are more than 3 feet deep. Plants down wind or down slope of social trails may be positively or negatively impacted, depending on the plant species. Many plant species can tolerate burial. For example, the instablitity of shoreline and perched dunes contribute to the survival of colonies of the federally threatened Pitcher's thistle (*Cirsium pitcheri*). The plant needs accumulating sand to thrive and if disconnected from a sediment source it will not thrive.

About five % of the total park budget is spent on dredging operations in rivers and adjacent to docks in Lake Michigan. The effects of disposal of dredged sediments on coastal sediment transport processes needs to be evaluated. Dredged sediment often appears to be coarser than shoreline sediments, and occasionally contains clay, which restrict sediment transport at these sites causing erosion down drift of dredge sites.

The ecological, human influence and management significance of this geoindicator are all considered high.

Soil quality

As one of the Earth's most vital ecosystems, soil is essential for the continued existence of life on the planet. As sources, stores, and transformers of plant nutrients, soils have a major influence on terrestrial ecosystems. Soils continuously recycle plant and animal remains, and they are major support systems for human life, determining the agricultural production capacity of land. Soils buffer and filter pollutants, they store moisture and nutrients, and they are important source and sinks for CO_2, methane and nitrous oxides. Soils are a key system for the hydrologic cycle and provide an archive of past climatic conditions and human influences.

Poorly developed soils in sand and gravel deposits left by glaciers resulted in rapid loss of soil nutrients through farming and logging. Land use has caused a transition from marginal to sub-marginal soil quality. Native forests were logged at the turn of the century and probably followed by fire. These depleted soils caused most farms in the area of Sleeping Bear Dunes to fail with the exception of orchards. Most of this region, including the islands, was farmed for a 40-year period. However, less than 10 % of the total park area was farmed. Port Oneida is a significant cultural landscape in the park. Established in the 1890's, the farms failed in the 1940's. The parks' cultural resource staff wants to reintroduce farming on some scale. The park needs to determine if reintroduction of farming practices in the park will further deplete the soil quality and related attributes.

A comprehensive soil survey was recently completed (1996) for Benzie County, and corrections were made to Leelanau County soil maps at the same time. The Natural Resource Conservation Service was responsible for conducting this soil mapping in the park.

Ecological significance is low. Due to the influence of humans on soil quality, human influence is considered high. Since soil quality is affected on less than 10% of land acreage of the park, management significance is low.

Landslides

Slope failure (landslides)

Landslides can damage ecosystems by altering or destroying habitat and resources downslope or downstream and can deliver sediment directly to stream channels. Slope failure is a natural process that can be induced, accelerated, or retarded by human actions. By understanding landslide processes and how human activities influence those processes scientists can identify landslide hazards and hopefully help predict future landslide activity.

Large landslides along coastal bluffs in Sleeping Bear Dunes National Lakeshore occur infrequently. Landslides have been well documented at Pyramid and Sleeping Bear Point. At Sleeping Bear Point slides have occurred in December 1914 (about 20 acres), March 1971 (25 acres) and February 1995 (2 acres). Studies by Jaffe (1998) indicate that the coastal landsliding at Sleeping Bear Point is not the result of undercutting of the slope by coastal waves, but is related to increases in pore water pressure in the sand bluff. During the winter, water from snowmelt may be trapped behind the frozen bluff face and pore pressures can increase enough to cause the bluff to fail. Water confined between clay layers at the base of the bluff may also trigger bluff failure. Results of these studies will help determine when slide danger at Sleeping Bear Point is high and access should be restricted. Also, interpretation of the results of the studies aimed at the general public will also educate and warn park visitors about the slide hazards of coastal bluffs.

Small-scale landslides also occur in the dunes and along the bluff faces overlooking Lake Michigan. The park has observed a several small failures along the coastal bluffs. These failures tend to be small rotational slumps along the shoreline and may include trees and vegetation. This process is active on the islands too.

During the winter, accumulations of snow and sand have resulted in slab avalanches in the park. In the late 1970's and early 1980's there were several avalanches which occurred in the Dune Climb area. In one of these incidents, a young boy was buried in deep snow for an extended period of time, but survived. Occasionally, sand/snow cornices can form and fail. One sand/snow cornice approximately 150 feet long was observed and when it failed it slumped and ran out a considerable distance, just south of the main Dune Climb.

Human influence on slope failures like Pyramid and Sleeping Bear Point is considered low. Typically, there are warning signs prior to failure, but landslides pose a potential hazard to park visitors. Management significance is considered moderate.

Other Geoindicators

Sediment sequence and composition

Lakes, wetlands, estuaries and other bodies of fresh or marine water commonly accumulate deposits derived from bedrock, soils, and organic remains within the drainage basin. Fine particles can be blown in by winds from distant natural, urban, and industrial sources. These aquatic deposits may preserve a record of past or on-going environmental processes and components, both natural and human-induced.

The stratigraphy of wetlands, lakes and dunes record natural prehistoric changes in paleo-climate and vegetation. Cores in wetlands and lakes provide pollen, spores and seeds, and other micro- and macrofossils in water laid sediments to reconstruct paleo-environments. Sediment deposits can provide an indication of the degree and nature of impacts of past events on the system and a baseline for comparison with contemporary environmental change. Some wetlands in the park have been cored and pollen analyses completed by Ken Cole, USGS. Recently a study of pollen and carbon was completed at Indiana Dunes and the report should be available.

Studies in Canada suggest that dune mobility is tied to fire. While the relationship between fire and dune mobility has not been studied in the park, more than one-third of the paleosols (ancient soils) in the dunes contain charcoals. The presence of charcoal indicates that fire is a process that has occurred in the park, but its extent and occurrence are not known.

Critical questions for the parks can be answered from a study of sediment cores to:1) develop a general picture of plant succession in the Holocene, 2) evaluate the relationship of fire and dune stability, and 3) determine if the inundation and subsequent death of shoreline forests associated with high lake level stands is a normal sequence.

Information contained in sedimentary sequences is high from an ecological perspective for providing a reconstruction of the paleo-environment and setting. The human influence on this process is low. However, its significance to management is moderate since sediment sequence may provide information on which to evaluate and determine the validity of re-establishment of a fire regime in the park as defined in the parks Fire Management Plan.

References

Boyle, T.P. and Hoefs, N.J., 1993, Water Resources Inventory of Sleeping Bear Dunes National Lakeshore, National Park Service, Baseline Water Quality.

Handy, A.H. and Stark, J.R., 1984, Water Resources of Sleeping Bear Dunes National Lakeshore, Michigan: U.S. Geological Survey Water-Resources Investigations Report 83-4253, 39 p.

Jaffe, B., Kayen, R., Gibbons, H., Hendley, J.W., and Stauffer, P.H., 1998, Popular beach disappears underwater in huge coastal landslide – Sleeping Bear Dunes, Michigan: U.S. Geological Survey Fact Sheet-020-98.

Loope, W.L. and Arborgast, A.F., 2000, Dominance of an ~150-year cycle of sand supply change in late Holocene dune-building along the eastern shore of Lake Michigan: Quaternary Research, v. 54, p.414-422.

Thompson, T.A. and Baedke, S.J., 1997, Strand-plain evidence for Late Holocene lake-level variations in Lake Michigan: Geological Society of America Bulletin, v.109, p. 666-682.

Wagner, J., 1998, Notes on SLBE 7/20-23, 1998 Trip Report. Sleeping Bear Dunes National Seashore Trip Report, 4 p.